Design parameters for deep stabilized soil evaluated from in-situ and laboratory tests

La détermination des paramètres dans le laboratoire et in-situ pour le sol stabilisé par la consolidation dynamique

K. KUJALA, Research Assistant, University of Oulu, Finland
H. HALKOLA, Geotechnical Engineer, Geotechnical Department of the City of Helsinki, Finland
P. LAHTINEN, Senior Research Engineer, Technical Research Centre of Finland, Espoo, Finland

SYNOPSIS Deep stabilization has been used and researched in Finland since 1974 and the experiences have so far been good. However, especially the question how to evaluate the parameters of the stabilized object and choice of proper design methods still require further research. With the determination of the design parameters, esp.of shear strength and compressibility, the aim has been to evaluate these in laboratory using samples taken in-situ. This has not, however, proved to be easy. Samples mixed in laboratory have in some cases given values deviating greatly from in-situ measured values, mostly so that the in-situ values are greater. In addition to differences in the mixing process, the laboratory-blanded samples also deviate in respect to temperature and pressure from the stabilized column made in-situ.Especially the temperature proved essential in the strengthening of the column. By imitating the temperature forming in the columns in the laboratory testing procedure, the laboratory results significantly better correlate to the in-situ values. The present paper gives research results on the effect of temperature on strengthening, as well as comparisons on how humus and sulphur content is decreasing the strength of lime stabilized clay and, also observations on the effect of air, formed in the column during construction, on the compression of the column.

INTRODUCTION

Deep stabilization is a good technique for strengthening of foundations on soft clay, for improving slope stability and for decreasing settlements. The deep stabilization technique used on Finland was invented in Sweden in 1967. (Broms, Boman 1978).

Deep stabilization has been used in Finland on building projects for about ten years with constantly increasing and diversifying applications. Follow-up measurements have been carried out during several years on many deep stabilization projects. In order to analyze the projects and control the measurement methods, comparative calculations have been performed (Lahtinen, Vepsäläinen, 1983), (Lahtinen, 1984). The research has been carried out also on actual building projects. Subjects of research were:

- various applications of deep stabilization
- various stabilizing agents and the effects of their quantities
- the suitability of laboratory and in-situ research equipment
- the effect of the composition of clay on the strengthening
- the effect of the temperature on the strengthening
- the determination of design parameters of deep stabilized soil
- the suitability of calculation and measurement methods.

The determination of design parameters of deep-stabilized soil has proved to be a most demandning task. The definition of the parameters evaluated from samples mixed in laboratory seems to lead to too great a dispersion and too small values compared to the values obtained from in-situ measurements. The present paper deals with the latest results obtained in the clarification work on the determination of design parameters in Finland.

DETERMINATION OF DESIGN PARAMETERS FROM LABORATORY TESTS

The mechanical properties of deep stabilized soil depend on the physico-chemical properties of the soil to be stabilized and on those of the stabilizing agent, and on the strengthening time and conditions. The shear strength of clays stabilized in laboratory varied at age 1 year from 10 to 100 kPa (Kujala, 1984). Sediments of the Litorina Sea, to which a high humus content, in addition with a high sulphur content is characteristic, showed only little strength gain with stabilization. Also the strength of very heavy clays remained poor.The best strengthening soils were silty clays with low content humus. For design purposes, strength and deformation parameters as well as the optimum amount of stabilizing agent have to be defined for each soil type of the site to be improved by deep-stabilization, using test samples stabilized in laboratory. It was, however, peculiar to the laboratory determined design parameters that they were often significantly lower than those obtained from columns stabilized in-situ. The worst correlation was in general found for the modulus of elasticity (Figure 1).

The effect of temperature

The difference between the parameters of the laboratory and in-situ stabilization is mainly

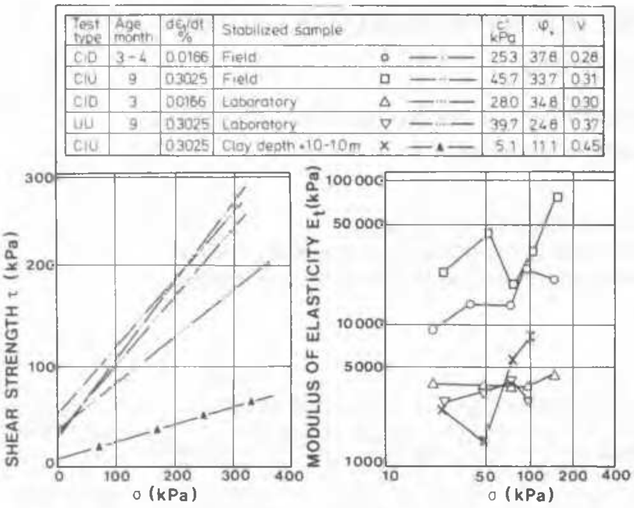


Fig.1. Shear strength and modulus of elasticity of clay limestabilized in laboratory and in-situ.

caused by the temperature during the early strengthening period. The binding agent used with deep stabilization is unslaked lime, which strongly reacts with water by releasing heat. The temperature of the lime columns in-situ varies greatly (Figure 2).

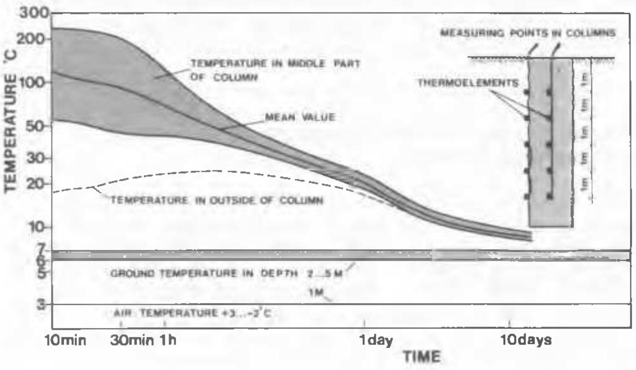


Fig.2. The temperature of a lime column as the function of time.

Maximum temperature of about 240°C were measured. The temperature in the columns evens out slowly and still after two weeks it is some degrees above that of the surrounding soil. In laboratory conditions similar early strengthening temperatures are not reached, because the stabilizing agent is usually mixed with a mechanical mixer in open vessels giving quicker temperature equalization and heat dissipation.

The higher the temperature the stronger it effects the strength and deformation parameters of stabilized soil (Figure 3). Raising the temperatures from +7°C to 20°C will increase the shear strength about 4 times and the modulus of elasticity close to 5 times. In order to receive better correlation between laboratory and in-

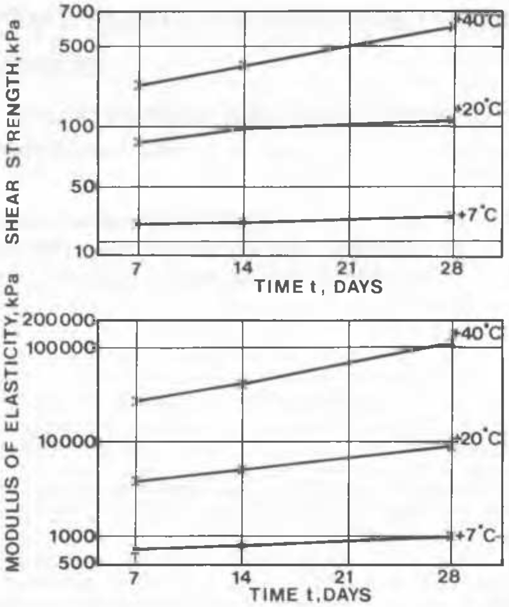
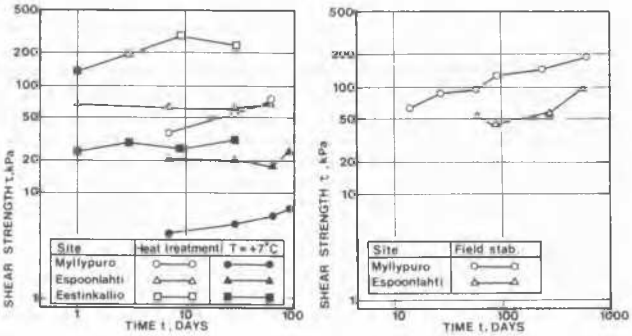


Fig.3. The effect of temperature on shear strength modulus of elasticity of lime-stabilized clay.

situ parameters, the temperatures of the test samples should in the early strengthening period better correspond to the temperature of the in-situ column. Figure 4 gives a summary of the test results where the early strengthening temperatures have been changed to correspond with the temperatures of the in-situ columns. This gives a much better correlation of test results.



a) Stabilized in laboratory   b) Stabilized in-situ

Fig.4. Strength of stabilized clays as a function of time.

The strong effect of the temperature on strength and compressibility is based on the changes in the mineralogy of the stabilized soil. This can be observed among other things as mineral differences for instance between temperatures +7° and +20°C (Kujala, 1984). The effect of the temperature can also be seen in the micro structure of the clay as a strong aggregation of clay particles into regularly shaped hexagonal plates.

The proportion of air in the columns

Due to the construction of the lime columns they contain a lot of air, the proportion of which in the volume change tests was nearly half of the total volume change (Figure 5). It is essential to the air content of the lime columns that most of it slowly leaves the column at a certain stage of loading. Here several local fractures occur in the micro structure of the stabilized soil, settling the granular framework and pressing the air from the sample. Greater than calculated settlements have thus been observed in certain deep stabilization sites, when the dimensioning of the stabilized soil was based on the elasto-plastic model (Lahtinen, 1984). The reason for these greater settlements may therefore be the amount of air leaving the columns when the load has exceeded a certain limit value.

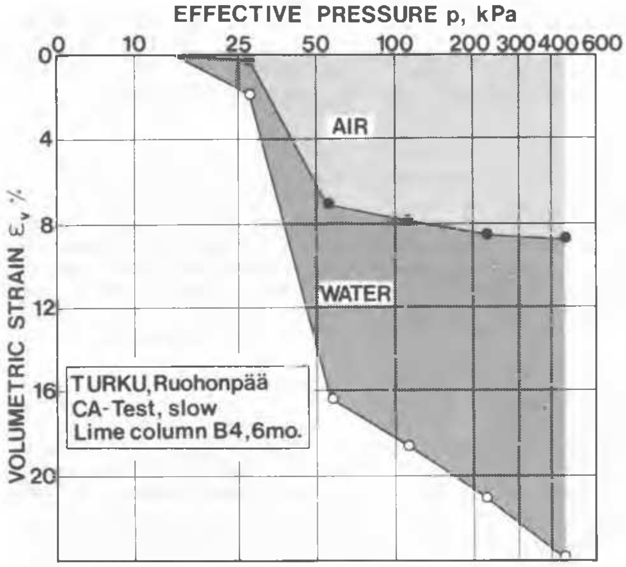


Fig. 5. Proportion of air in the volume change of a lime column in an anisotropic volume change test.

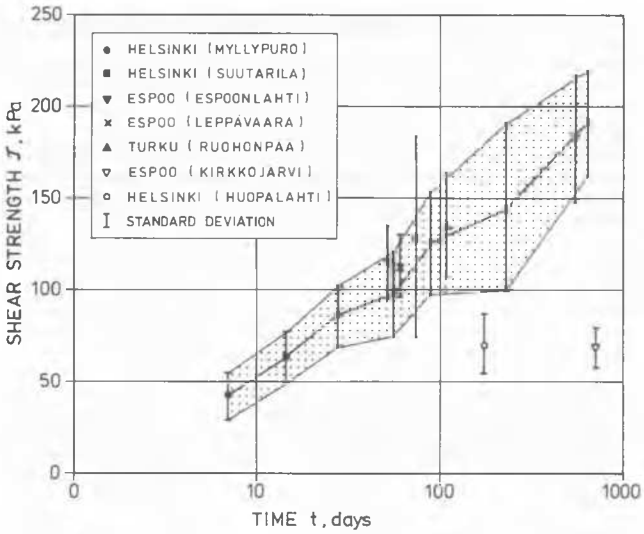


Fig.6. Strength of lime-stabilized columns at different times.

IN-SITU INVESTIGATIONS

Stabilization control and measuring shear strength

Control soundings are used for observation of the deep satbilized soil after the stabilization work is completed. The purpuse of the soundings is to investigate the quality of the stabilized soil and also the strength increase. In Finland investigations are performed using a purpose designed column-penetrometer (Torstensson, 1980) and special vane-bore for calibration of the penetration-test results (Halkola, 1983). Also a screw-plate compressometer (Janbu et al, 1973) is used. The results of the control soundings show that in clay areas, where the humus content is < 2 % and the sulphur content < 0.1 %, the strength increase (CaO as stabilizing agent) is almost similar (Figure 6, black points). When the humus and sulphur content is high, the strength increase is evidently smaller (Figure 6, white points).

Demands for the quality of the stabilization-work

Sounding results in different stabilization sites show that standard deviation of the strength of the stabilized soil is remarkable.The values for standard deviation have been observed to vary between 15 - 60 %. The scatter of the results depends on the stabilization equipment used and also on the stabilization site. It is recommendable to investigate at last 3 columns even in the smallest stabilization sites. In larger projects the suitable amount for investigated columns is 1 - 3 °/oo of all columns in the project. Usually control-soundings are made when the stabilized columns are 1 - 3 months of age. In the case the standard deviation of the sounding results exceeds 25 %, it is necessary to investigate more thoroughly how the stabilization work has succeeded for instance by taking samples from the columns. It is also possible to lift a whole column for an inspection (Broms et al., 1978).

Settlement behavior of deep-stabilized soil

The purpose of deep stabilization is to increase the shear strength and also to reduce the compressibility of the soil. So far it has proved to be difficult to obtain reliable design parameters, due to poor correlation between in-situ and laboratory results. Deformation modulus (E_u) for design purposes are usually obtained applying deformation results of already completed stabilized structures (Lahtinen et al., 1983). The modulus of elasticity of lime-stabilized columns in clayey ground in the Helsinki area has been observed to vary within the range of E = 15 000 - 25 000 kPa. The humus and sulphur content was low in the observed sites, and structures on stabilized areas were built when lime-columns were 3 - 9 months of age.

Also a screw-plate compressometer (with weights) has been used to determine the deformation modul- 'ith the screw-plate compressometer it is possible to load soil at different depths without excavations. Results of two screw-plate tests made in lime-stabilized columns are presented in figure 7. The calculated moduli of elasticity in the example are E = 22 000 kPa for a stabilized column 270 days of age and E = 170 000 kPa for a column 1000 days of age. Results of settlement observation at a test embankment in the same area (Helsinki, Myllypuro) have also been applied to calculate the moduli. These have been observed to vary within the range of E = 11 000 - 26 000 kPa. The stabilized columns were approximately 270 days of age when the test embankment was built. In screw-plate tests a Ø 160 mm plate is normally used, and because of the small effective depth of the vertical stress, local changes in the strength of a column affects strongly the results.

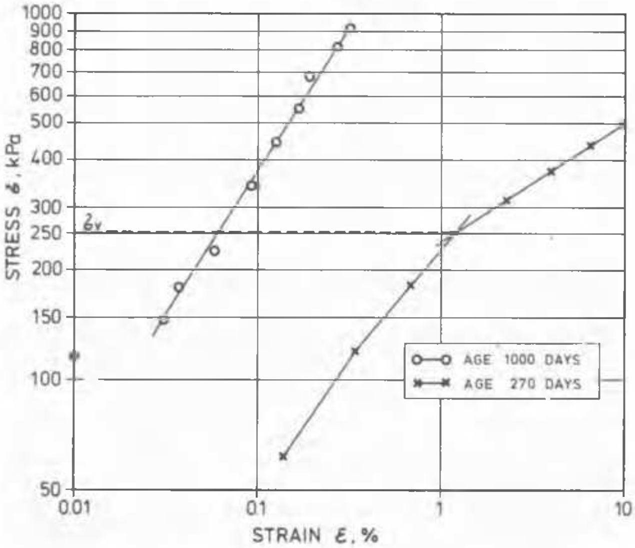


Fig.7. Example of screw-plate compressometer tests in lime-stabilized columns.

The creep-limit of a single column can also be obtained applying screw-plate results. When the creep-limit (σ_y) of a column is exeeded, the deformation strongly increases (Figure 7). In some cases it has proved to be very difficult to determine creep-limits from the screw-plate test results. The creep-limit is then considered to be the stress σ_y at a relative strain of $\epsilon = 1$ %.

In the near future, the long-term settlement behaviour of stabilized columns will be investigatred when the creep-limit is exeeded. It is expected that the air present in the micro structure of a column would be pressed out and cause large secundary compression. The total settlement of a stabilized area can then be equal to the settlement of an unstabilized area.

CONCLUSIONS

1. The research, in which in-situ and laboratory investigations have been compared, shows very clearly that if the parameters of deep stabilized soils are determined in the laboratory, the samples have to be stored at the same temperature which exist in the lime columns. Heat treatment makes it also possible to determine the development of strengthening of deep stabilized soil.
2. The composition of clay (especially the contents of sulphur and humus) have significant effect on the strengthening of lime stabilized soil. In the soft clays of the Helsinki area the strength gain has been relatively consistent when the content of sulphur is < 0.1 % and the content of humus < 2 %.
3. Investigation of lime columns in-situ has been involved for development of suitable equipments. The column-penetrometer and column vane-bore have proved to be good investigation equipments to determine the strength and its variation on lime columns. For the evuluation of compressibility the screw-plate compressometer has proved to be a most suitable toal.
4. During the construction of the lime columns rather much air remains entrapped. When the load of a lime column exceeds the creep load the settlements are speeded up apparently and at the same time air and water is compressed out to an increasing amount. Local fractures occur in the micro structure of the lime-column, and the column looses at least partly and temporarily its bearing capacity.

ACKNOWLEDGEMENTS

The writers wish to express their appreciation to the sounding personnel of the Geotechnical Department of the City of Helsinki as well as to the student of technology Juha Korpi´s valuable assistance.

REFERENCES

Broms, B., Boman, P. (1978). Stabilization of soil with lime columns, Design handbook.Royal Institute of technology, Stockholm, Sweden.

Halkola, H. (1983). In-situ investigations of deep stabilized Soil. Proc. 8th Conf. on ECSMFE, Helsinki, Finland.

Janbu, N., Senneset, K. (1978). Field compressometer-principles and application. Proc. 8th Conf. on ICSMFE, Moscow, USSR.

Kujala, K. (1984). Faktorer som inverkar på djupstabiliserade jordars mekaniska egenskaper Nordiska Geoteknikermötet, Linköping, Sweden.

Lahtinen, P. (1983). Djupstabiliseringens dimensionering. Nordisk Seminarium om djupstabilisering, Espoo, Finland.

Lahtinen, P. (1984). Calculating the Settlements on a deep stabilized site. Proc. 8th Conf. on ECSMFE, Vol 3, Helsinki, Finland.

Lahtinen, P., Vepsäläinen, P. (1983). Dimensioning deep stabilization using the Finite Element Method. Proc. 8th Conf. on ECSMFE, Helsinki, Finland.

Torstensson, B-A. (1980). The "BAT lime column proble" for in-situ testing of quality of lime columns. Linden Alimak AB, Skellefteå, Sweden.